In situ Study of Irradiation-Enhanced Diffusion in Nonproliferation Reactor Fuels

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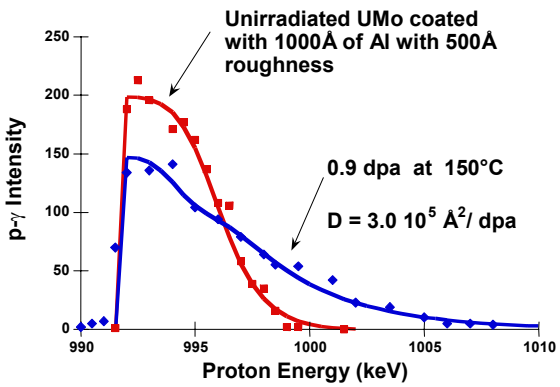
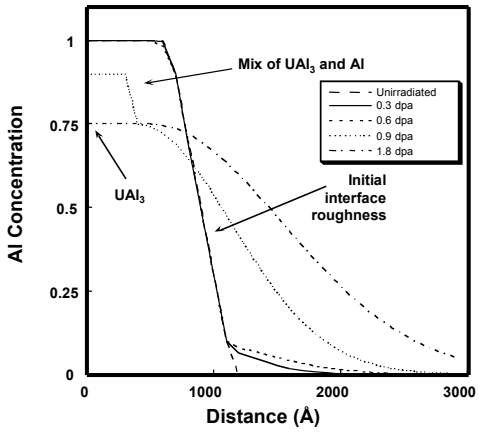
High-density uranium compounds have potential for use at low U^{235} enrichment as proliferation-resistant reactor fuels. Such low-enriched fuels are mandated for university reactors and as export fuels. A major problem with this class of fuels is irradiation driven reaction of the fuel with its cladding. In the worst case, this causes swelling and voiding leading to loss of cooling. To address this, we are using ion beam techniques in an in situ study of irradiation enhanced diffusion of Al into uranium molybdenum alloys. Such a detail study can not be done by reactor irradiations.

U-6wt.% Mo specimens were coated with 100 nm of Al and irradiated with 3 MeV Kr ions at a temperature of 150°C. Al concentration profiles were measured by the resonance nuclear reaction of $^{27}Al(p, \gamma)^{28}Si$. The gamma intensity from the resonance reaction was determined as a function of the incident proton energy. The energy loss as the protons penetrate deeper into the specimen allows sampling of the Al at different depths.



Gamma spectra before and after irradiation. Fits are based on diffusion profiles expected for the diffusion of a thin surface layer.

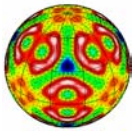


Al concentrations extracted from P-γ measurements before and after irradiation at 150C.

Deconvolution of these measurements yields the Al composition as a function of depth. Initial interface roughness was extracted from the slope of the curve before irradiation. Specimens were damaged by irradiation with increasing doses of 3.0 MeV Kr ions. This type of irradiation is an excellent simulation of the damage produced by uranium fission. Resultant gamma spectra were determined after each irradiation and fit with the Al diffusion profile expected for a thin surface layer; $C_{Al} = C_o\, e^{-(x2/Dy)}$ where C is the Al concentration, x is the diffusion distance, D is the irradiation enhanced diffusion constant and y is the ion dose in dpa.

Al diffusion during irradiation into UMo is rapid even at 150°C. The radiation-enhanced diffusion constant determined independently for all ion doses is $D = 3.0\ 10^3\ nm^2$ / dpa. This rapid diffusion is complicated by the formation of UAl_3. This phase formed after only 0.9 dpa at the initial Al/UMo interface. The rapid growth rate of this phase is approximately 50 nm / dpa. This results in consumption of Al on the surface. When the Al surface layer was consumed, the Al profile extended more than 3 μm into the U alloy.

This study will be extended to determine the activation energy for these processes from the temperature dependence of the interaction. The diffusion of Al following phase formation and the stability of the aluminide phase will also be determined.



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